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CRACK PROPAGATION STUDIES
OF WELDS IN
TANTALUM AND COLUMBIUM
SHEET

Final Report
Materials Sciences Laboratory

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CONTENTS

ABSTRACT

Single pass welds were prepared in 0.015-in.-thick tantalum (Ta) and columbium (Cb) sheet material by the automatic-inert-gas, non-consummable electrode (TIG) process, representing "best practice." Edges of the material were formed to provide filler material.

Tensile and precracked sheet Charpy tests were performed. Crack propagation resistance measurements were obtained for weld center-line, heat affected zone and base metal locations. Modes of failure were obtained and categorized. Both macroscopic and microscopic examinations were made of the weld zone, heat affected zone, and base metal.

TABLES

ILLUSTRATIONS

Section 1
MATERIAL

The material used for this investigation consisted of commercially pure 0.015-in. thick tantalum (Ta) and columbium (Cb) sheet. The sheet was sheared into 4-in. wide pieces. The edges of the material were formed at a sharp radius to provide filler metals. The sheets were then welded by the TIG process; manual hold-down with copper strips and "C" clamps with helium gas backup and cup were used.

Welding conditions were as follows:

	Ta	Cb
• Approximate current	70 amp	50 amp
• Approximate volts	16/18 volt	20 volt
• Travel speed	30 ipm	30 ipm

X-rays were taken of the welded panels to determine if porosity or cracks were present. Linear porosity was found in some of the welds in the tantalum material and scattered porosity was found in some of the welds in columbium. The porosity in the welds was not severe enough to affect test results. No cracks or voids were observed in any of the welds tested. Weld width and root data are shown in Table 1.

Photomacrographs and photomicrographs were made of the welds in both materials. The etchant used in the photomicrographs was made of 100 parts H_2O + 7.5 parts HF + 2.5 parts HNO_3. Etch time was slightly over 1-1/2 hr.

Weld structures of the tantalum and columbium sheet are shown in Figs. 1 through 11.

Section 2
SPECIMEN PREPARATION

2.1 TENSILE SPECIMEN

Six coupons were prepared from both the columbium and tantalum sheet. The coupons were divided so that three were prepared where the weld was parallel to the principal rolling direction and three where the weld was transverse to the principal rolling direction (layout of the tensile specimens are shown in Fig. 12).

2.2 SHEET CHARPY SPECIMENS

Sheet Charpy specimens, as shown in Fig. 13, were prepared from both the columbium and tantalum sheet. The specimens were prepared where the weld was parallel to the principal rolling direction and where the weld was transverse to the principal rolling direction.

The specimens were sheared to ~2.200 in. long and 0.450 in. wide. Three specimens were then laminated together, using a 0.015-in. thick columbium spacer and an unfilled epoxy cement (W. T. Bean epoxy, cement-type RTC). Specimens were cemented and spring clamped together and the cement cured for 1 hr at 175°F. Specimens were layed out so the notch location was in the following area:

(1) Base metal
(2) Weld centerline
(3) Weld edge
(4) 0.010 from weld edge
(5) 0.020 from weld edge
(6) 0.030 from weld edge
(7) 0.060 from weld edge
(8) 0.125 from weld edge
(9) 0.250 from weld edge

Specimens were machined to specifications shown in Fig. 13.

Section 3
TESTING PROCEDURES

Tensile coupons were tested at room temperature using a Tinius Olsen Universal test machine, Model 120, and a load cell adapter for 300 lb full scale. The specimens were marked for a 1-in. gage length. A Tinius Olsen clip-on extensiometer, Model S3, with a 1-in. gage was attached to the specimen. The output of the extensiometer was recorded on the X axis and load recorded on the Y axis of a Model 51 Olsen recorder.

Impact testing of the sheet Charpy specimens was performed on a 24 ft-lb capacity, Man Labs, Inc. subsize impact testing machine.[1] The unit employs a compound pendulum design which eliminates the normally used light supporting shaft and places the center of percussion at the lowest extremity of the pendulum. Extreme rigidity is thus achieved in both the pendulum and anvil, and the possibility of specimen jamming is largely eliminated. The machine is mounted on a concrete base, weighing approximately 1500 lb, thus providing the testing machine with an "infinite" base which is capable of absorbing any required loss of energy from the machine during testing. On the low energy range of the machine, sensivity of energy loss of the specimen is 0.008 ft-lb and at higher energy, lowest sensivity is 0.02 ft-lb. The striking velocity of the pendulum is 11.5 ft/sec.

The pendulum is held by a catch in its raised position, at which time the specimen is placed squarely on the anvil using a set of centering tongs to handle the specimen. With the pointer set at zero, the pendulum is then released by the release knob. The pendulum then swings down freely in a clockwise direction, hitting the specimen and continuing on with its remaining energy. The pointer is moved up scale and rests at the apex of the pendulum swing-through. A vernier scale on the pointer permits reading of the angle to .10 degrees; this angle is then converted into ft-lb energy

(absorbed by the specimen) using an appropriate graph or the equation

$$E = 11.8472 + 12.03 \cos \alpha$$

where

E = absorbed energy, ft-lb

α = observed angle, degrees

Section 4
RESULTS AND DISCUSSION

4.1 TENSILE TESTS

As shown in Table 2, tests performed on the transverse weld tensile blanks indicate that the tensile yield strength and ultimate strength of the tantalum welds are more than 50% higher than the values in the columbium welds.

Specimen orientation with respect to the principal rolling direction appears to have little or no effect on the tensile yield strength or the ultimate strength of the material.

Total elongation of the tantalum sheet is almost twice that of the columbium.

Necking down and failure occur predominantly in the base material (Fig. 14). In only two cases did the failure occur in the weld fusion zone.

4.2 IMPACT BEND SPECIMENS

Shown in Tables 3 and 4 are the results of tests performed on the impact bend specimens containing notches in select regions in and adjacent to the weld zone. These results indicate that the crack tear energy is significantly higher in the tantalum weldments than in the columbium. Both, however, exhibit exceptionally high values. The lowest toughness in the tantalum weldments appears to be in the mid region of the weld fusion zone. The lowest toughness in the columbium weldments appears to be at the edge of the fusion zone/heat-affected zone. The tests of these specimens disclose these welds are so tough that excessive plastic deformation and tendency for the specimen to buckle predominate. It was not possible to obtain characteristic crack propagation energy measurements because of the excessive plastic deformation.

As shown in Fig. 15, the plane stress fracture toughness of metals like these tested rises to a peak value for a given thickness and then decreases exponentially to some minimum value as t increases. The thickness of the material tested in this program falls in the area shown by "all plane stress" of the curve (Fig. 15). The elastic constraint on the crack front of this thin material is low, due to the lateral dimension. Therefore, the material undergoes larger plastic flow at the crack tip; thus, the propagating crack requires additional energy to be applied.

Section 5
CONCLUSIONS

A. Fracture toughness of welds in thin sheets of both tantalum and columbium is sufficiently high to give little concern.

B. The fracture toughness in tantalum is significantly higher than in columbium.

C. Because of excessive plastic deformation, characteristic crack propagation energy measurements can not be obtained with sheet Charpy impact specimens from 0.015-in. thick Cb and Ta sheet even by using the laminated sheet Charpy specimens.

D. Propagation of a through-thickness crack in Ta and Cb thin sheet due to tensile stress applied normal to the crack involves buckling of the sheet, which absorbs additional energy. This buckling promotes tear resistance of the sheet.

Section 6
REFERENCES

1. Lewis, R. E., "Fracture Toughness as Influenced by Phase Transformations in Manual Welds in AM-350 Steel Sheet," LMSC Report No. 2-60-64-13, Apr 1964

2. Arnold, S. V., "A Laminated Specimen for Charpy Impact Testing of Sheet Metal," Proceedings ASTM 57, 1957, pp. 1273 – 1281

3. Irwin, G. R., "Relation of Crack-Toughness Measurements to Practical Applications," Welding Journal, 41, No. 11, Res. Supp., Nov 1962, pp. 519S – 528S

4. Irwin, G. R.. "Theoretical Aspects of Failure Analysis," ASM Metals Engineering Quarterly, 3, No. 1, Feb 1963, pp. 24 – 30

5. Irwin, G. R., J. A. Kies, and H. L. Smith, "Fracture Strengths Relative to Onset and Arrest of Crack Propagation," Proceedings ASTM 58, 1958, pp. 640 – 660

Table 1

TANTALUM AND COLUMBIUM SHEET WELD DATA

Panel	Weld Length (in.)	Weld Direction (from R.D.)	Bead Width			
			Face		Root	
			max.	min.	max.	min.
T1	15-5/8	L	0.094	0.080	0.090	0.066
T2	12	T	0.106	0.092	0.098	0.068
T3	11-1/2	T	0.098	0.092	0.092	0.046
T4	11-7/8	T	0.128	0.082	0.094	0.072
C1	15-3/8	L	0.104	0.090	0.098	0.086
C2	11-1/4	L	0.080	0.054	0.076	0.040
C3	7-3/8	T	0.072	0.068	0.066	0.054
C4	7-3/8[a]	T	0.092	0.068	0.086	0.056

(a) Burnout between 3-1/8 and 3-7/8 in. from start of weld

Table 2

TENSILE SPECIMEN TEST RESULTS

Material	Weld Orientation (a)	Specimen	Tensile Yield Stress (b)	Ultimate Tensile Stress	Elongation (in 1 in.)	Location of Failure (c)
Ta	Parallel	TT01	34,047	50,000	0.334	C
		TT02	35,714	48,333	0.300	C
		TT03	35,238	46,904	0.283	C
Ta	Perpendicular	TL01	33,250	49,750	0.243	C
		TL02	37,375	51,500	0.340	C
		TL03	36,500	51,000	0.248	C
Cb	Parallel	CT01	20,000	31,410	0.193	C
		CT02	19,102	31,666	0.150	C
		CT03	18,846	31,410	0.154	C
Cb	Perpendicular	CL01	20,000	30,384	0.161	C
		CL02	18,718	31,026	0.192	W
		CL03	18,461	30,256	0.118	W

(a) With respect to principal rolling direction in sheet. All specimens transverse to weld

(b) 0.2% offset

(c) C = specimen necked down and failed at end of gage length
W = failed in weld fusion zone

Table 3

TANTALUM SHEET CHARPY IMPACT TEST RESULTS

Weld Orientation[a]	Notch Location	Specimen	Crack Propagation Energy[b]	Fracture Class[c]
Transverse	B.M.	T1T01	3730	1 + 5
	Weld Centerline	T2T01	2760	2 + 5
	Weld Edge	T3T01	3095	2 + 5 + 6
	0.010 in HAZ	T4T01	3903	1 + 3
	0.020 in HAZ	T5T01	4006	1 + 5 + 6
	0.030 in HAZ	T6T01	2881	1 + 3
	0.060 in HAZ	T7T01	4697	1 + 3 + 6
	0.125 in HAZ	T8T01	4766	1 + 4 + 5 + 6
Transverse	0.250 in HAZ	T9T01	3905	1 + 4 + 5 + 6
Parallel	B.M.	T1L01	2817	1 + 3 + 6
	Weld Edge	T3L01	2720	2 + 3
	0.010 in HAZ	T4L01	2331	1 + 3 + 6
	0.020 in HAZ	T5L01	2262	1 + 3 + 6
	0.030 in HAZ	T6L01	3336	1 + 3
	0.060 in HAZ	T7L01	3329	1 + 4 + 6
	0.125 in HAZ	T8L01	3675	1 + 5 + 6
Parallel	0.250 in HAZ	T9L01	2676	1 + 5 + 6

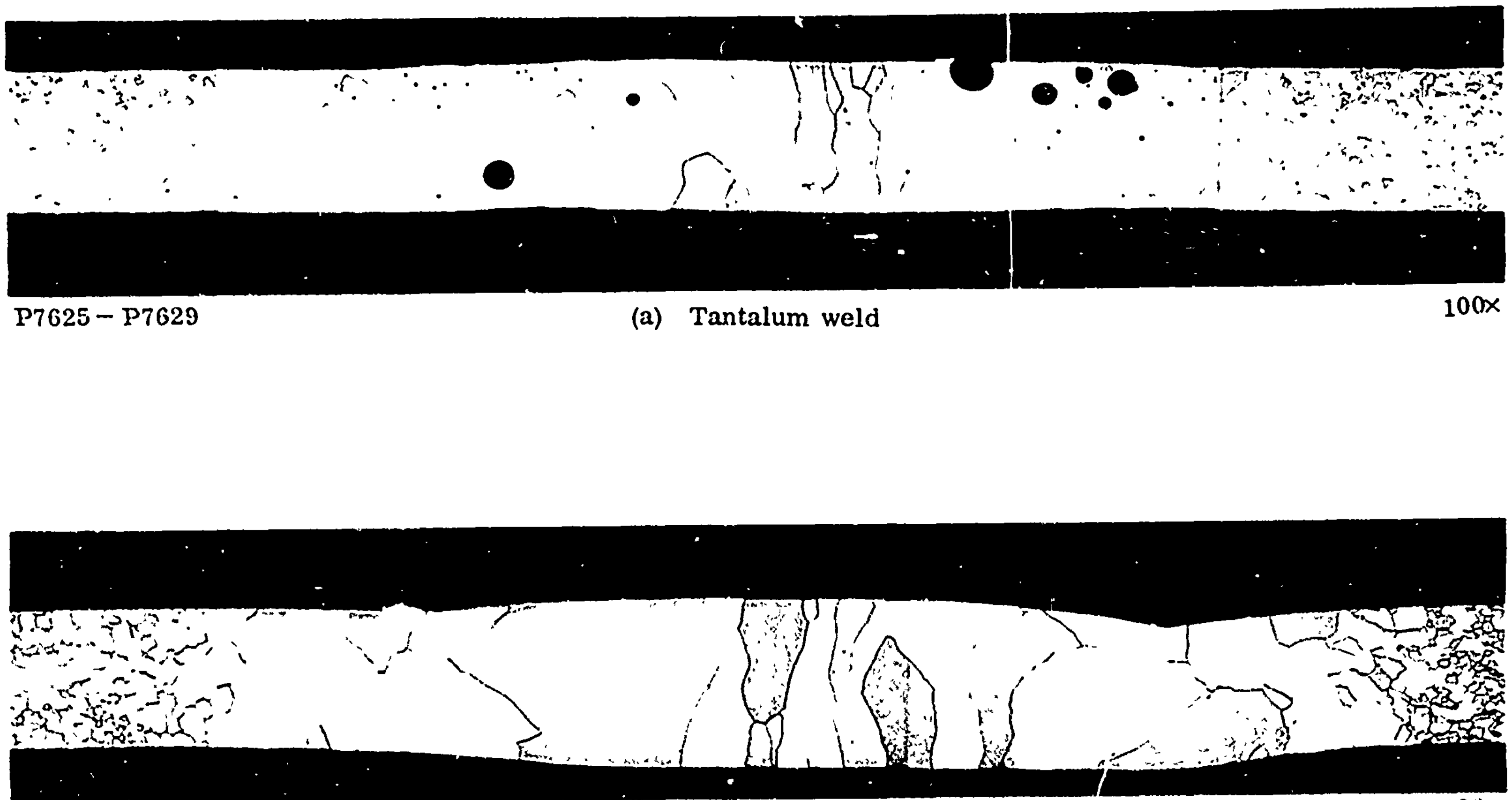
(a) With respect to principal rolling direction of metal
(b) Crack propagation energy in in.-lb/in.^{2}. Computed using average of three laminated specimens; calculations also include distortion energy where applicable
(c) Fracture-classification (see Fig. 16)
1 = Tearing fracture surface necking down to a "knife edge"
2 = Mixed mode fracture, partially type 1 above with some intercrystalline and/or transcrystalline fracture
3 = Buckled severely out of plane. Tearing fracture less than half way through specimen depth
4 = Specimen buckled moderately (<20°) out of plane
5 = Tearing fracture path almost through entire depth of specimen (within 1/16 in. of base of specimen), no buckling of specimen, except slight amount at hinge
6 = Slight crushing of specimen edge where contacted by the Tup.

Table 4

COLUMBIUM SHEET CHARPY IMPACT TEST RESULTS

Weld Orientation[a]	Notch Location	Specimen	Crack Propagation Energy[b]	Fracture Class[c]
Transverse	B.M.	C1T01	2170	1 + 5
↑	Weld Centerline	C2T01	1860	2 + 5
	Weld Edge	C3T01	1809	2 + 5
	0.010 in HAZ	C4T01	1775	2 + 5
	0.020 in HAZ	C5T01	1930	2 + 5
	0.030 in HAZ	C6T01	1855	2 + 5
	0.060 in HAZ	C7T01	2017	1 + 5
↓	0.125 in HAZ	C8T01	2015	1 + 5
Transverse	0.250 in HAZ	C9T01	2103	1 + 5
Parallel	B.M.	C1L01	2939	1 + 4 + 5 + 6
↑	Weld Edge	C3L01	2327	2 + 5 + 6
	0.010 in HAZ	C4L01	1941	2 + 5
	0.020 in HAZ	C5L01	2623	2 + 5
	0.030 in HAZ	C6L01	1924	2 + 5
	0.060 in HAZ	C7L01	2394	1 + 5
↓	0.125 in HAZ	C8L01	2231	1 + 5
Parallel	0.250 in HAZ	C9L01	2231	1 + 5

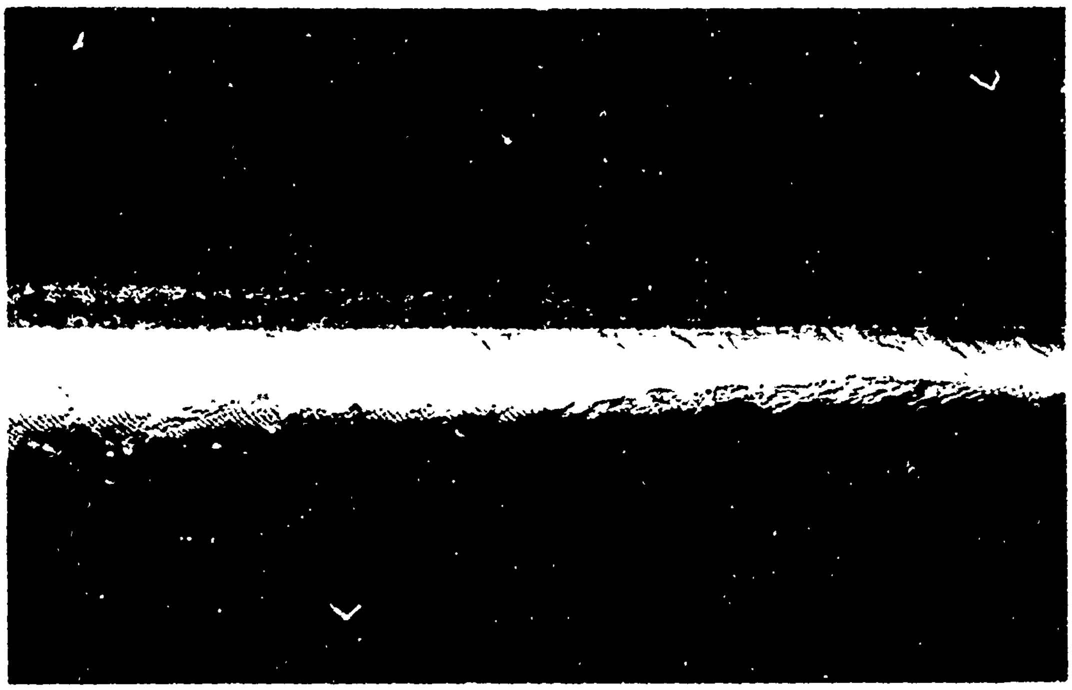
(a) All notes same as Table 3



P7625 – P7629 (a) Tantalum weld 100×

P7573 – P7577 (b) Columbium weld 100×

Fig. 1 Panorama of Microstructure Through Weld Zones in Tantalum and Columbium Sheet (Reduced 45% in reproduction)

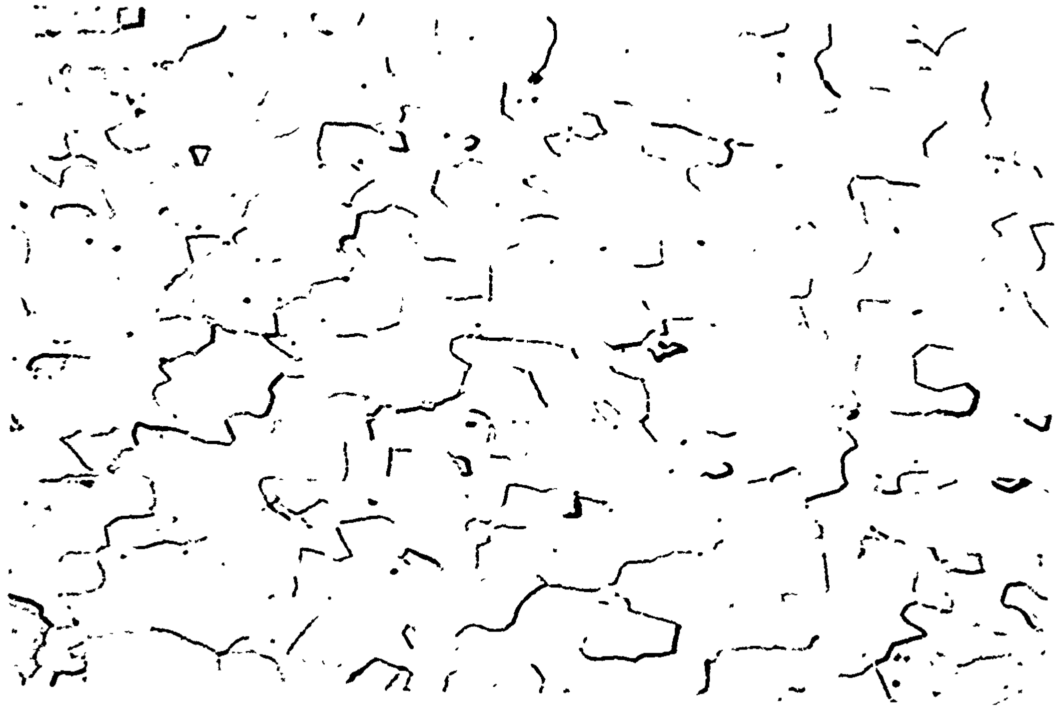


P7374

Fig. 2 Top Surface of Tantalum Weld

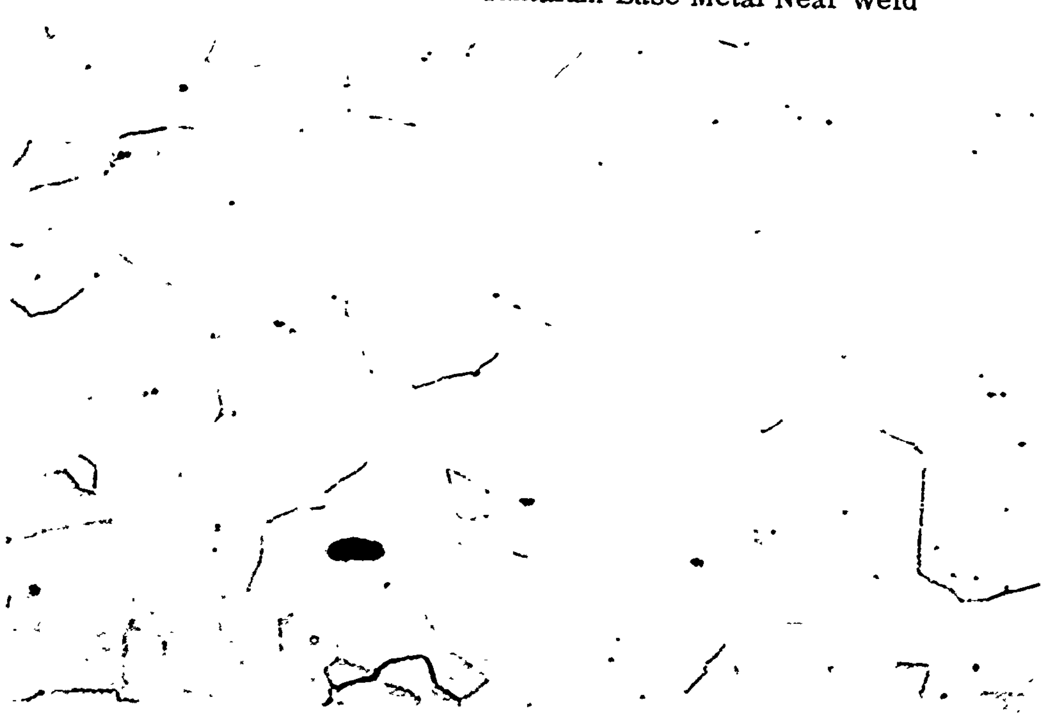
P7375

Fig. 3 Bottom Surface of Tantalum Weld (porosity shown was worst condition found)



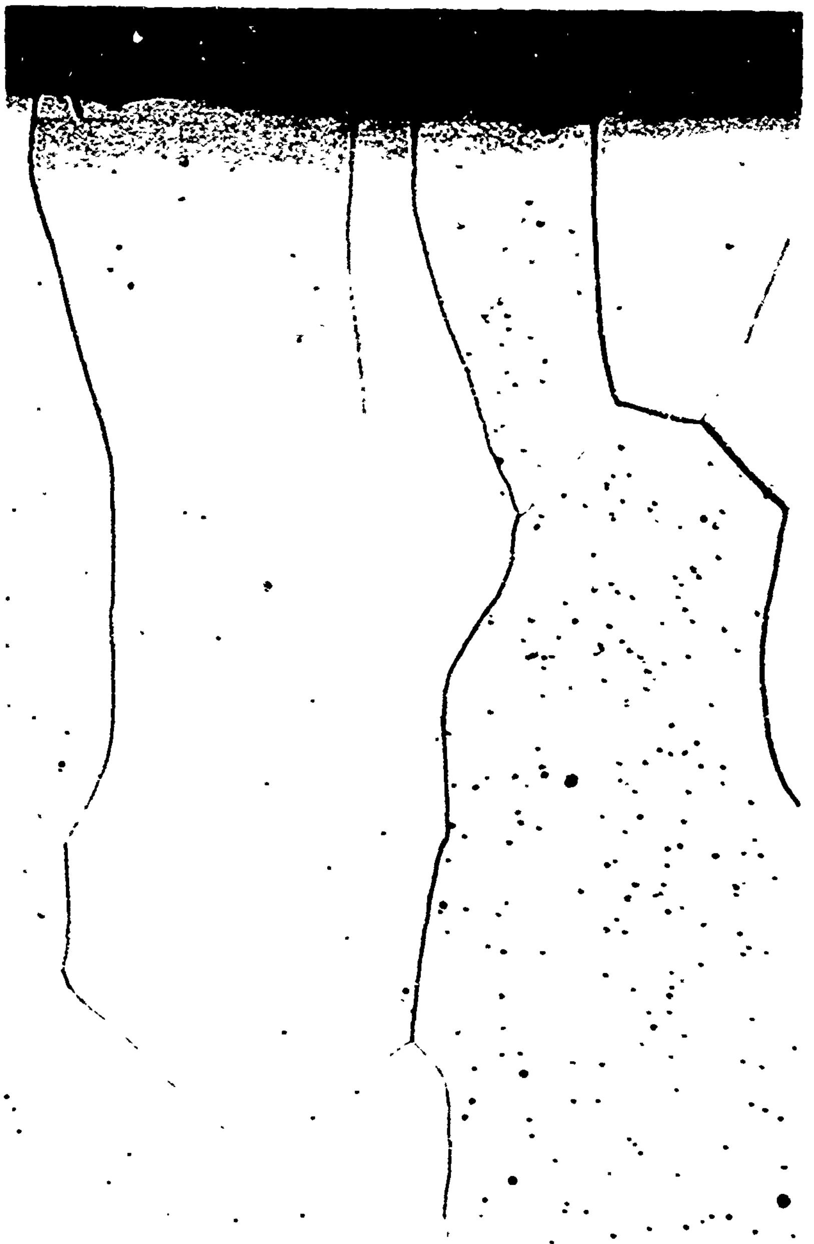
P7630 500×

Fig. 4 Microstructure of Tantalum Base Metal Near Weld



P7631 500×

Fig. 5 Microstructure of Tantalum in Heat-Affected Zone

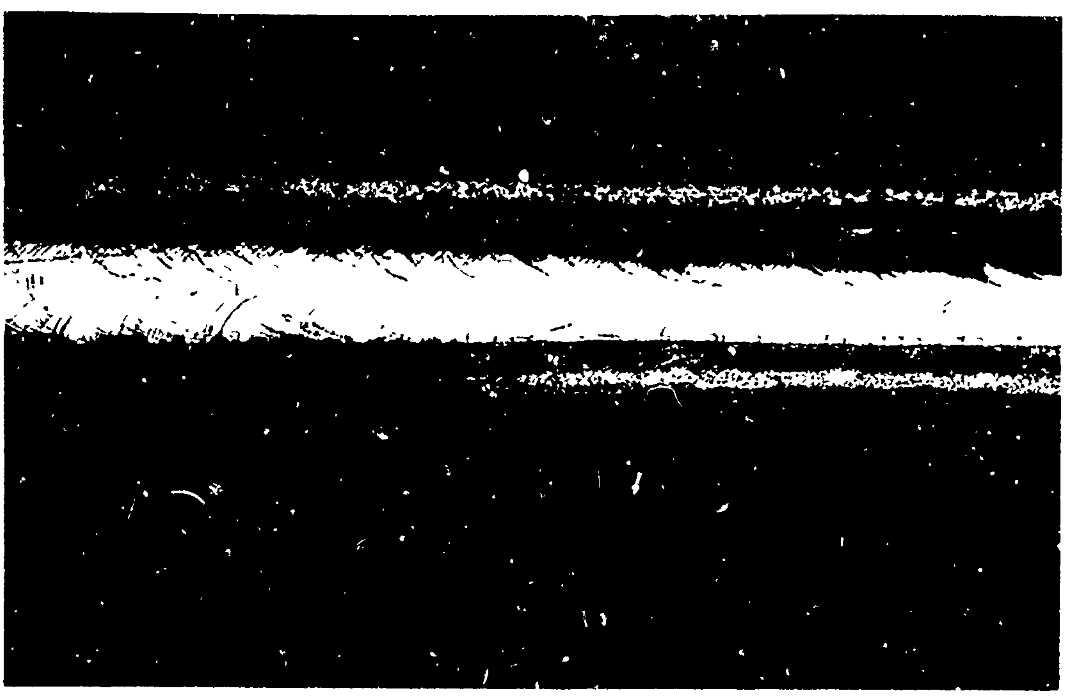


P7632 500×

Fig. 6 Microstructure of Weld Center in Tantalum

P7377

Fig. 7 Top Surface of Columbium Weld



P7376

Fig. 8 Bottom Surface of Columbium Weld

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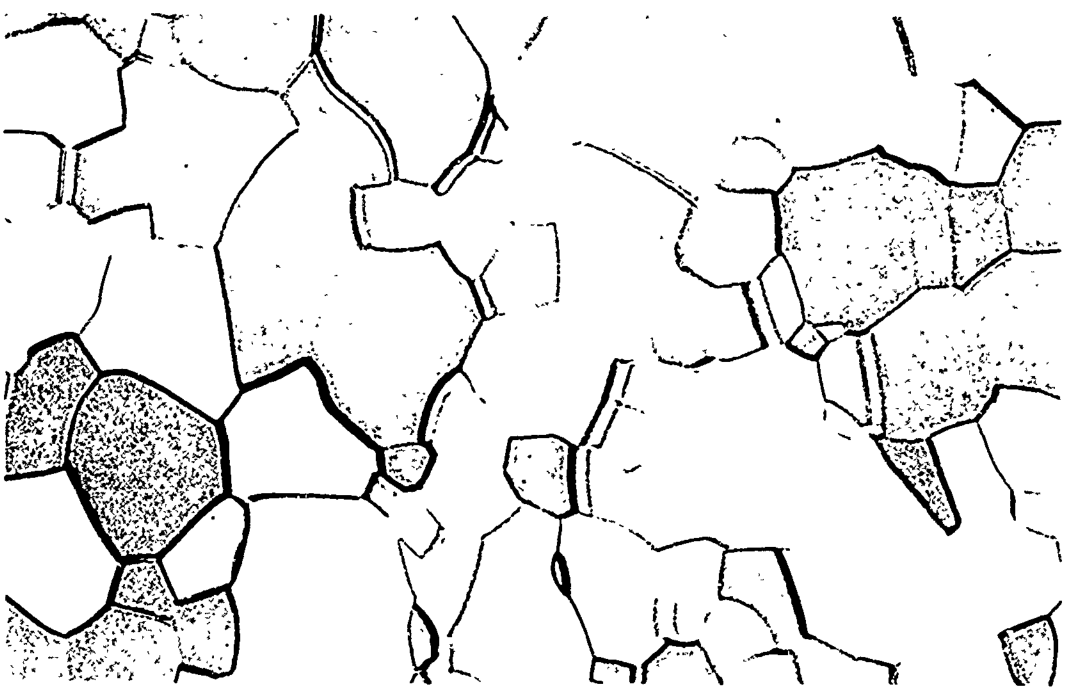
LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

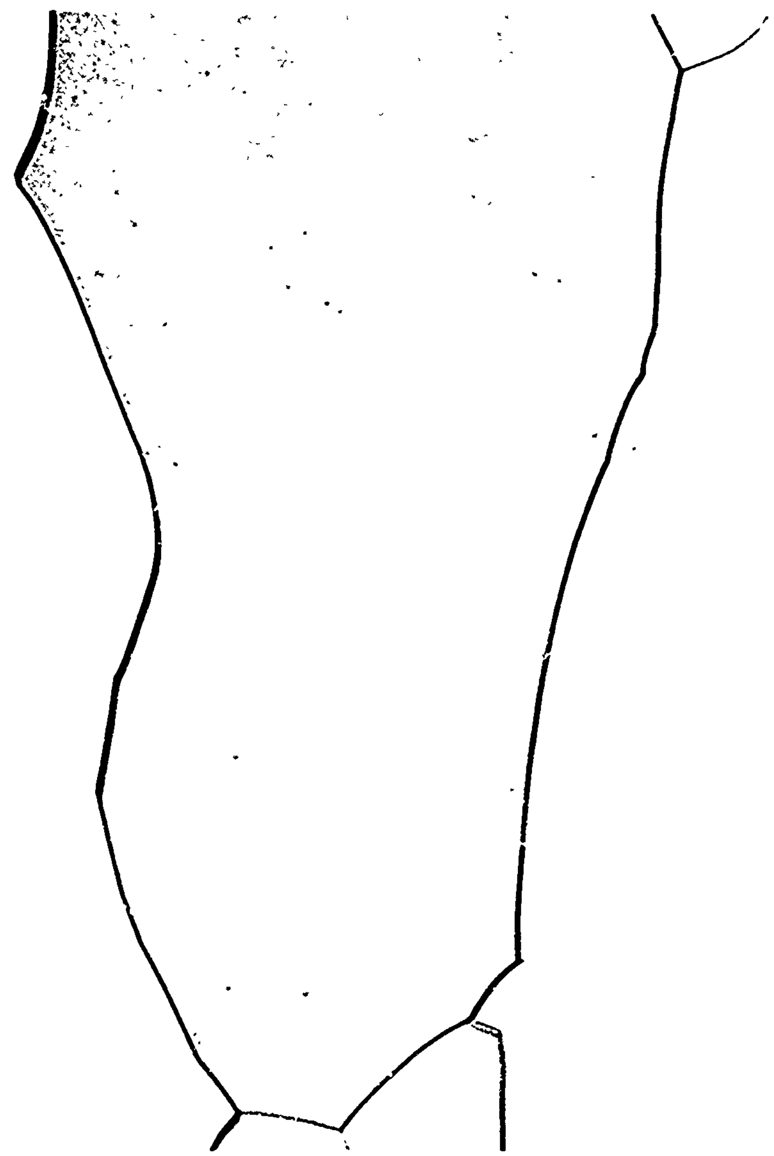
P7579 500×

Fig. 9 Microstructure of Columbium Base Metal Near Weld



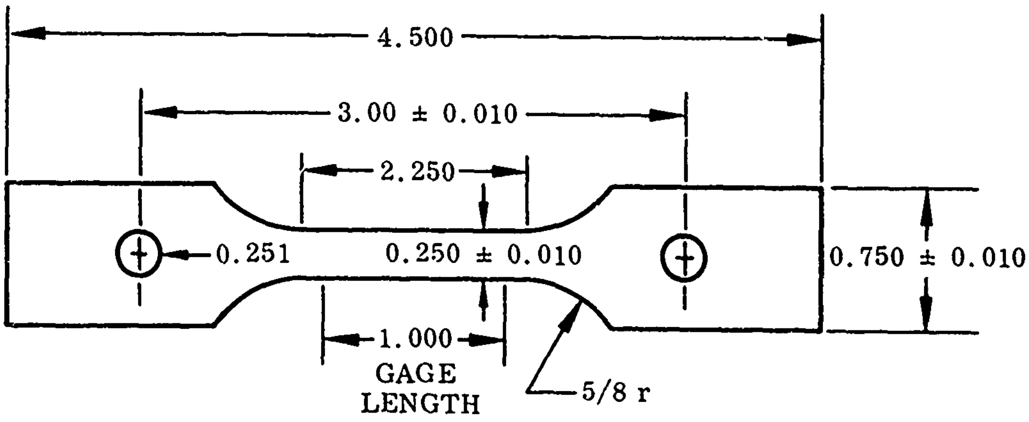
P7578 500×

Fig. 10 Microstructure of Columbium in Heat-Affected Zone



P7577 500×

Fig. 11 Microstructure of Weld Center in Columbium



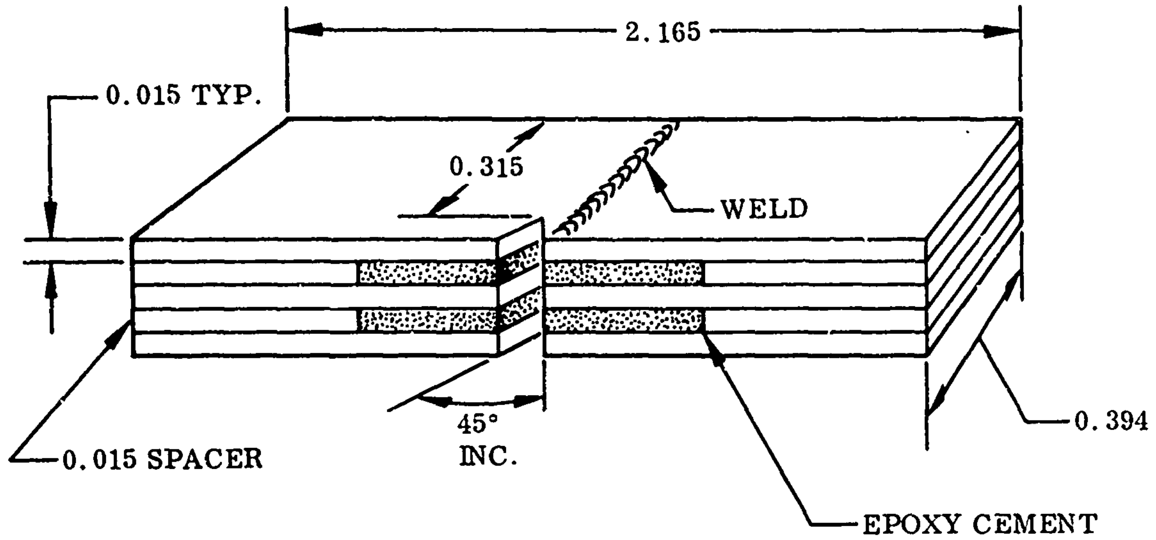
NOTES:

1. Ends of reduced section not to differ in width by more than 0.002 in. Neither end shall be narrower than center, nor shall it be greater than 0.005 in. than the center.

2. Ends of the specimen shall be symmetrical with the centerline of the reduced section within 0.005 in.

3. Weld zone located midway along gage length and transverse to specimen.

Fig. 12 Tensile Specimen Used For Tensile Tests

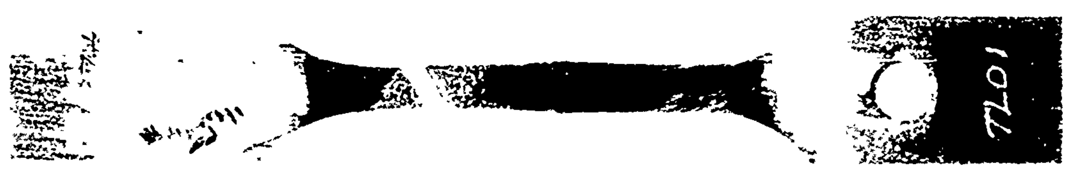


NOTES:

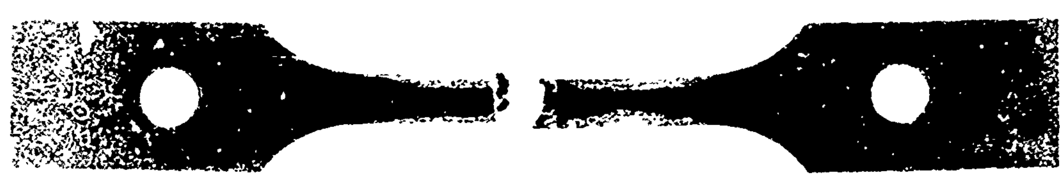
1. Material: 0.015 tantalum and columbium sheet, laminated with unfilled epoxy.
2. Adjacent sides to be parallel within 0.001 in.
3. Maximum surface roughness: notch 63, sides 32.
4. Notch centerline marked on specimen by requestor.

Fig. 13 Laminated Sheet Charpy Specimen

Ta SPECIMEN TRANSVERSE TO ROLLING DIRECTION



Ta SPECIMEN PARALLEL TO ROLLING DIRECTION



Cb SPECIMEN TRANSVERSE TO ROLLING DIRECTION

Cb SPECIMEN PARALLEL TO ROLLING DIRECTION

Fig. 14 Typical Tensile Specimen Fracture Appearance

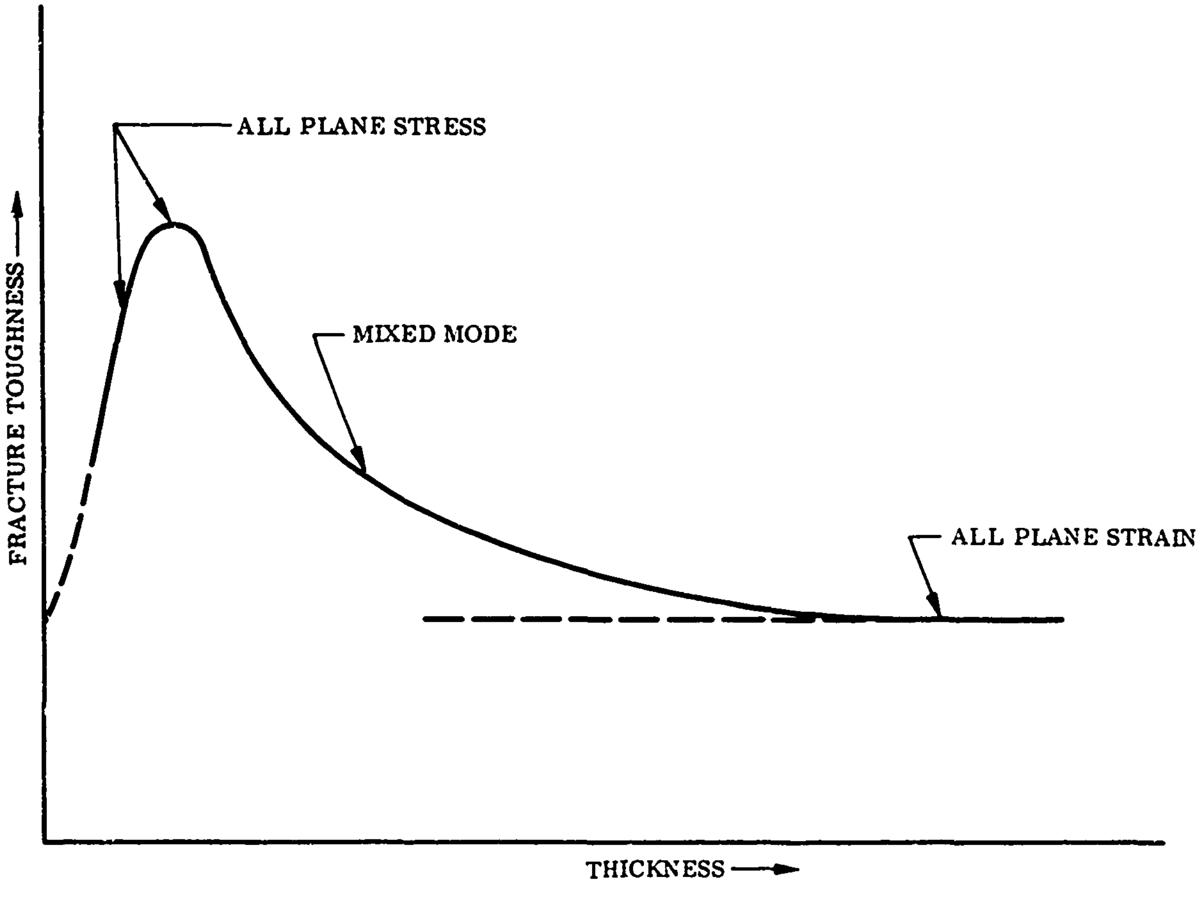


Fig. 15 General Relationship Expected Between Fracture Toughness and Specimen Thickness for Center-Notched or Edge-Notched Specimens

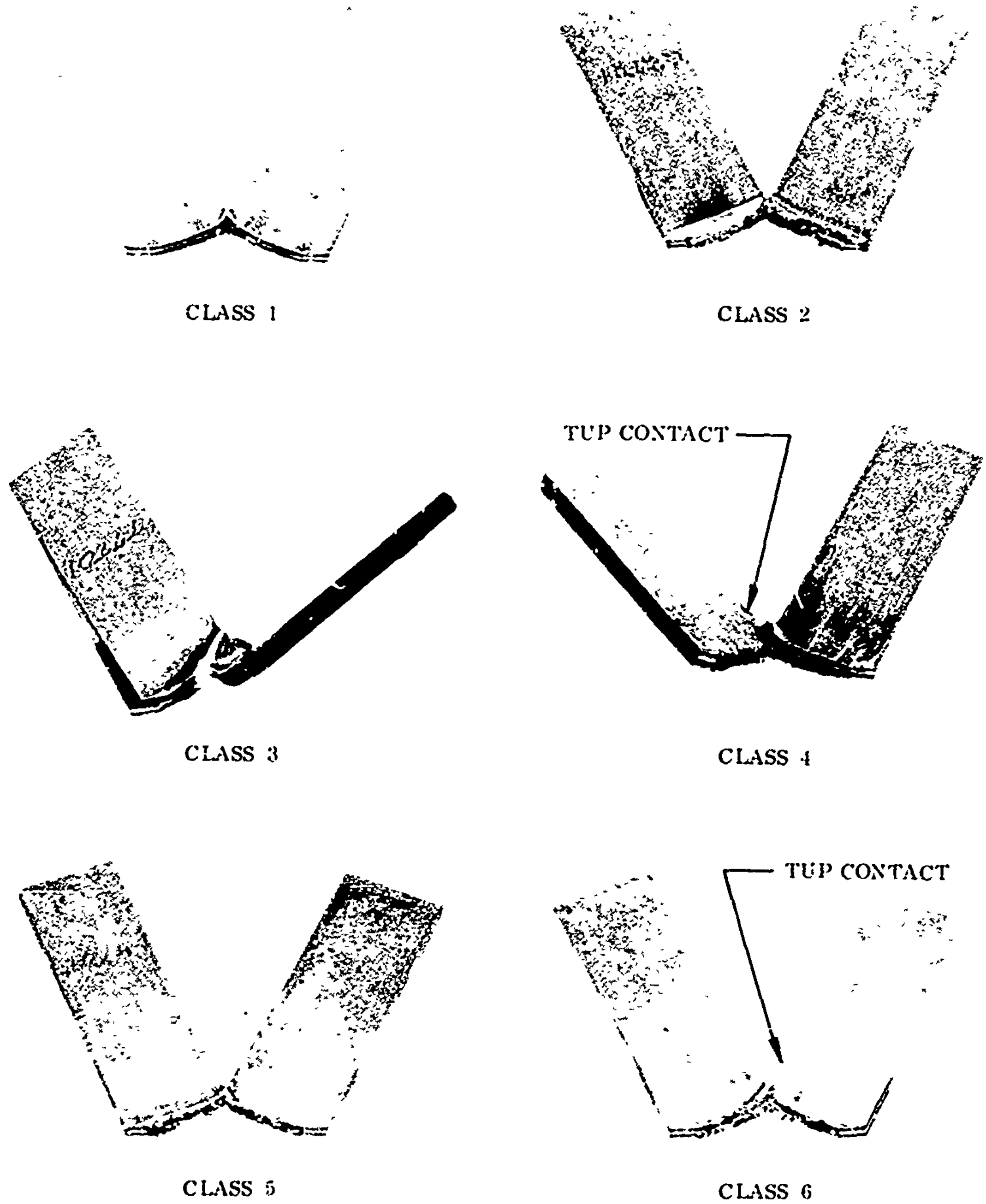


Fig. 16 Sheet Charpy Fracture Classification Assigned in Present Study